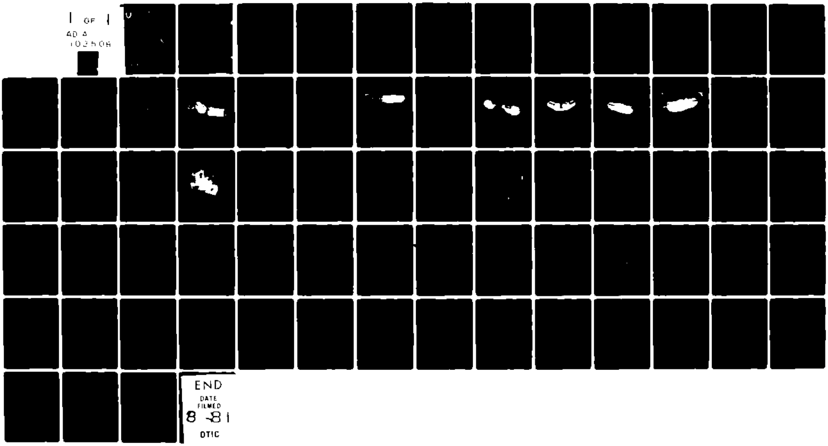
AD-A102 508 TRW INC PHILADELPHIA PA F/G 20/6
OPTICAL FIBER COMMUNICATIONS CABLE CONNECTOR.(U)
JUL 81 J G WOODS DAAK80-79-C-0772
UNCLASSIFIED CORADCOM-79-0772-F NL



LEVEL III

(12)

RESEARCH AND DEVELOPMENT TECHNICAL REPORT

CORADCOM- 79-0772-F

AD A102508

OPTICAL FIBER COMMUNICATIONS CABLE CONNECTOR

John G. Woods
TRW INC.
Electronic Components Group
Research and Development Laboratories
Philadelphia, Pa. 19108

July 1981

FINAL REPORT FOR PERIOD MAY 1979 - FEBRUARY 1981

DTIC FILE COPY

DISTRIBUTION STATEMENT
Approved for public release;
distribution unlimited.

Prepared for:
CENCOMS

CORADCOM

US ARMY COMMUNICATIONS RESEARCH & DEVELOPMENT COMMAND
FORT MONMOUTH, NEW JERSEY 07703

81 8 05 81

NOTICES

DISCLAIMERS

The citation of trade names and names of manufacturers in this report is not to be construed as official Government indorsement or approval of commercial products or services referenced herein.

DISPOSITION

Destroy this report when it is no longer needed. Do not return it to the originator.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER: CORADCOM-79-0772-F	2. GOVT ACCESSION NO.: AD-A102 508	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): Optical Fiber Communications Cable Connector		5. TYPE OF REPORT & PERIOD COVERED: Final Report 1 May 1979-17 Feb 1981
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): John G. Woods		8. CONTRACT OR GRANT NUMBER(s): DAAK80-79-C-0772
9. PERFORMING ORGANIZATION NAME AND ADDRESS: TRW, Inc. Electronic Components Group Research & Development Laboratories 401 North Broad Street, Philadelphia, PA 19108		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 612701.H92.MA.11.20
11. CONTROLLING OFFICE NAME AND ADDRESS: CORADCOM CENCOMS (DRDCO-COM-RM-1) Fort Monmouth, NJ 07702		12. REPORT DATE: July, 1981
		13. NUMBER OF PAGES: 66
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): DCASMA Philadelphia P. O. Box 7730 Philadelphia, PA 19101		15. SECURITY CLASS. (of this report): Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release: distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Recipients of this report are requested to forward comments and/or recommendations concerning technical aspects of this effort to address in Item 11

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

connector
fiber optic
cable connector
fiber optic connector
optical fiber connector
optical fiber communications

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A six channel hermaphroditic connector, which will function with 125μm to 150μm diameter optical fibers, has been designed, constructed and tested. The report includes the principal aspects of design, including the incorporation of the TRW Cinch Optalign "double elbow" fiber alignment guide concept.

Means for connecting either Siecor or ITT six fiber cable were developed.

DD FORM 1473 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. ABSTRACT (cont'd)

The use of ITT cable required the development of methods for stripping the jacket and buffer layer from each fiber, and applying a protective trimethylchlorosilane coating to retain inherent glass fiber strength.

The rapid and simple connector assembly procedures for the final model are described, as well as the unique fiber scribe and cleave tool which was designed specifically for use with this connector.

Typical insertion loss levels obtained with the ITT cable are approximately 1.0 dB, seldom greater than 1.5 dB. The results of vibration, thermal shock and mating durability tests are discussed.

Accession For
NTIS GRA&I
DTIC TAB
Unannounced
Justification

By
Distribution/
Availability Codes
Dist | Avail and/or Special
A

PREFACE

This final report describes the work on a six channel fiber optic connector, performed for the U. S. Army Communications and Electronics Command (CECOM), Center for Communications Systems (CENCOMS), Fort Monmouth, New Jersey, under Contract number DAAK80-79-C-0772, by TRW, Inc., Electronic Components Group, Research and Development Laboratories. TRW/Cinch Connectors Division performed the design and fabrication of the connector hardware.

TABLE OF CONTENTS

APPENDIXES

LIST OF ILLUSTRATIONS

LIST OF TABLES

1.0 INTRODUCTION

The objective of the optical fiber connector program is to demonstrate, through design and construction of working connectors, a low loss means of making demountable connectors between multiple fiber cable sections, or between cable and bulkhead receptacles.

Primary requirements for the connector are:

1. Ease of assembly.
2. Hermaphrodicity.
3. Less than 1.0 dB insertion loss.
4. Vibration, MIL-STD-202E, method 204C, Condition A (1.524mm amplitude, or 10g, 10 to 500 Hz).
5. Thermal shock, MIL-STD-202E, *Method 107D, Condition A* (-55^{o}C, 25^{o}C, 85^{o}C, 25^{o}C).
6. Mating durability: 1000 cycles. Free running nut torque, < .085 Nm.

This report includes discussions of the basic design concepts involved in the 6 channel connector, as well as the construction and testing of a prototype connector for Siecor cable, and the final design, construction and testing of 10 connector halves for ITT cable.

Some of the work described in the report has been reported at two conferences in 1980[7,8].

2.0 BACKGROUND

TRW has developed a unique approach to the connection of single optical fibers, utilizing a patented four rod glass alignment guide, which has been described in detail in earlier reports[1,2]. Brief descriptions of the alignment guide and the single channel Optalign connector are given here, as background information for the description of the six channel connector.

2.1 The Alignment Guide

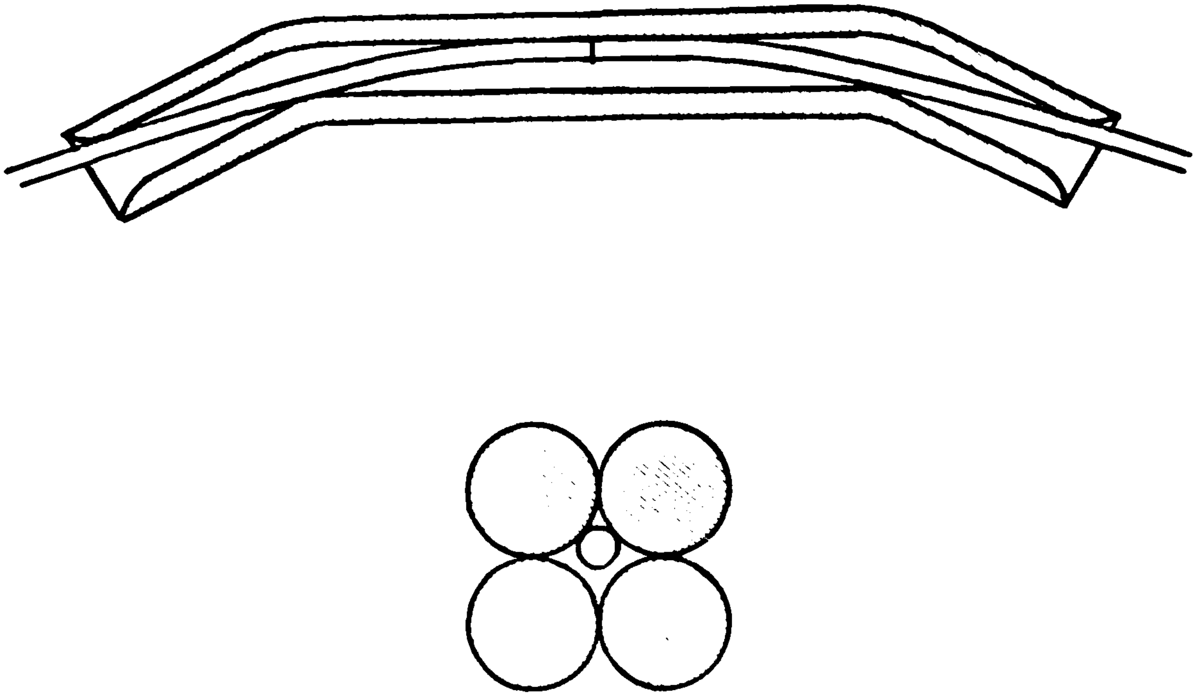
The TRW patented four rod glass alignment guide can be described as a ferrule/v-groove device, which provides a loose fitting channel to guide the fibers into an alignment v-groove.[3] Figure 1 is a schematic diagram showing the principle of the fiber alignment guide. The two fibers are fed into the ends of the guide, and forced toward the top cusp by the double elbow configuration. The geometry of the guide is such that normal tolerances of molded or machined parts achieve sufficient location accuracy of the fiber ends to prevent angular or gap losses in the fiber connection.

2.2 The Single Channel Connector

A single fiber connector incorporating the four rod alignment guide is manufactured by TRW Cinch Connectors Division[4]. A sectional view of this connector, called the Optalign$^{(R)}$

TRW FIBER ALIGNMENT GUIDE

LENGTHWISE SECTION



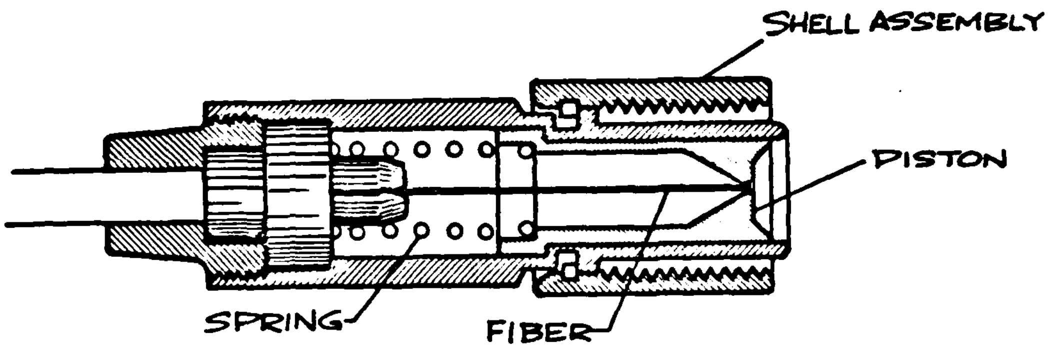
END CROSS SECTION

(ENLARGED)

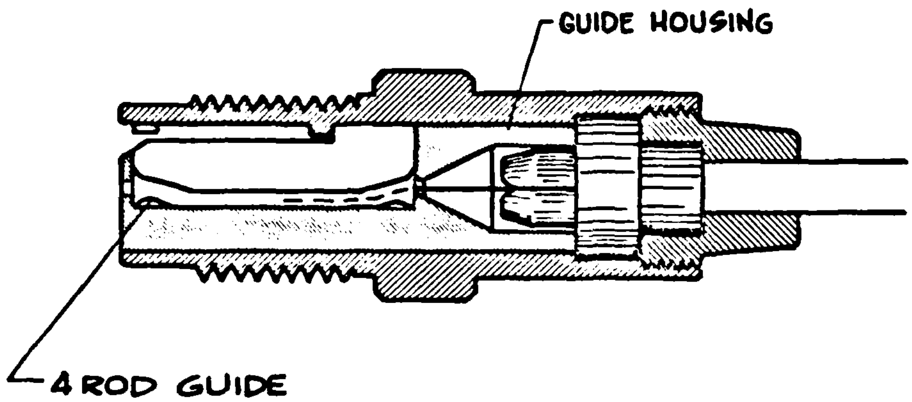
Figure 1

is shown in Figure 2. The guide is enclosed in an injection molded plastic slug which is retained in the aluminum receptacle shell by the molded fiber clamp and aluminum retaining nut. The plug assembly contains a plastic piston, which slides in the aluminum shell, and is spring loaded to protect the fiber end until the guide slug pushes it back as the connector is mated. Upon mating of the connector, the fiber in the plug enters the end of the four rod guide in the receptacle. As the coupling nut is rotated to pull the two shell halves together, the fiber moves through the guide channel and is forced along the same v-groove, or cusp, in which the receptacle fiber end lies. The two fiber ends meet near the center of the four rod guide. To assure physical contact of the fiber ends, for minimum loss, an overtravel of .025 to .508 mm is allowed. The resulting bend in the fiber serves to relieve the stress and maintain low constant pressure at the fiber junction. The overtravel range is controlled by proper dimensioning and minimizing tolerance buildup between the faces of the fiber clamps. The fibers are cleaved to $\pm$ .076 mm of their nominal from the clamp faces.

The Optalign$^{(R)}$ connector provides a simple connection system utilizing an easy scribe/cleave fiber preparation process. The readily assembled connector gives repeatable results through the use of the four rod alignment. guide. These factors led us to design the six channel connector using the internal parts of the Optalign$^{(R)}$ connector.



PLUG ASSEMBLY



RECEPTACLE ASSEMBLY

Figure 2

OPTALIGN(R) CONNECTOR

3.0 THE SIX CHANNEL CONNECTOR

3.1 Prototype Design and Construction

A six channel connector was designed, utilizing the Optalign(R) principle and internal parts. A cutaway view of the prototype connector is shown in Figure 3, as well as a photograph of the assembled unmated connector in Figure 4. Hermaphrodicity is obtained by placing three guide slugs and three spring loaded pistons in identical holders in each connector shell. The slugs are located in one half of a circular array and the pistons in the other half.

Both connector halves are identical in design, each shell having a coupling nut to engage the three interdigitated threaded segments of the mating shell. The block holding the pistons and slugs is stepped to key with the identical block in the mating connector half.

In the prototype sample, which was designed to connect Siecor six fiber cable, the cable is retained by an internally threaded plastic nut, which is twisted on to the outer cable jacket. The six stripped optical fibers are fed through the fiber clamps spaced around a plastic clamp holder. The clamp holder, (or tree) and assembled clamps, provide the means for retaining the individual fibers for accurately scribing and breaking each fiber prior to insertion into the separate fiber guides and pistons.

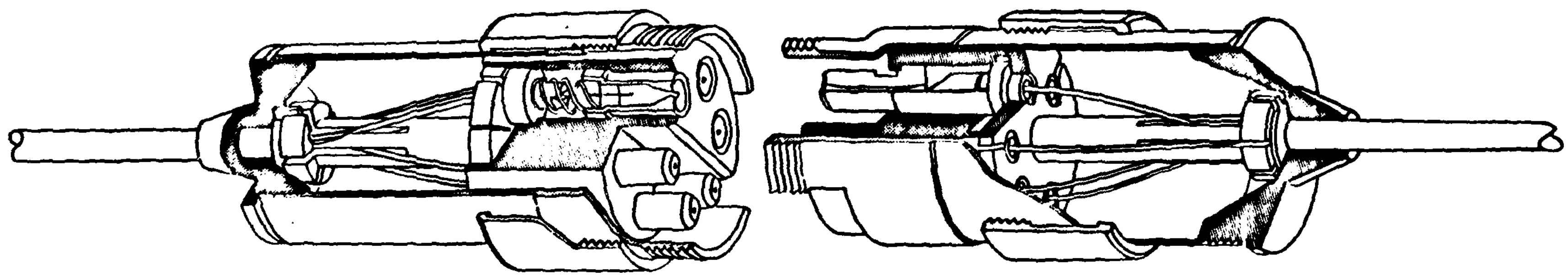


Figure 3

6 CHANNEL CONNECTOR

PROTOTYPE - CUTAWAY VIEW

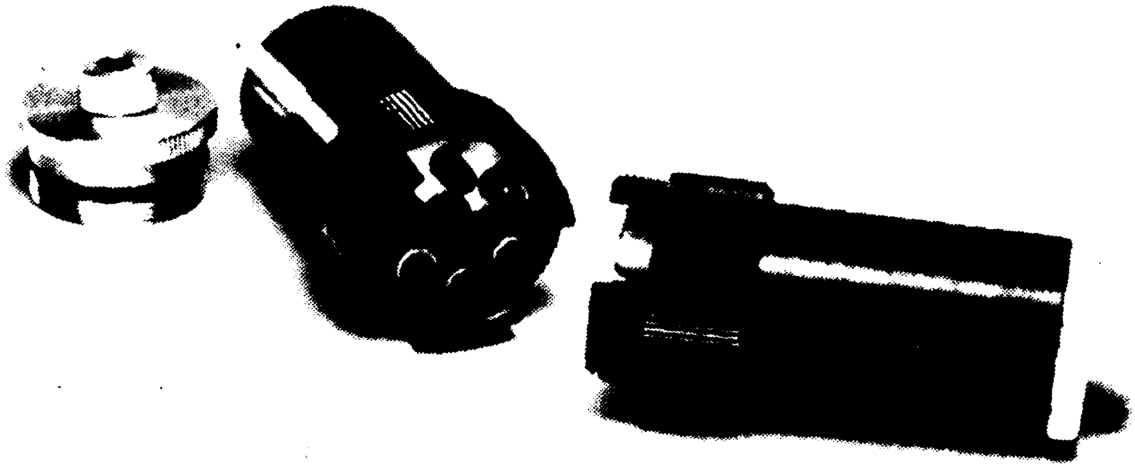


Figure 4
6 CHANNEL CONNECTOR
PROTOTYPE MODEL - UNMATED

After cleaving the fibers, the clamp holder is snapped into the slug/piston block. The entire internal assembly, from the rear cover and cable clamp to the slug/piston/block assembly, is then inserted in the shell/coupling ring assembly and the rear cover is screwed into the shell.

3.2 Design Improvements and Added Features

During the design, construction and evaluation of the prototype, several areas for improvement were identified, including some changes requested or suggested by CORADCOM.

The major change requested by CORADCOM was to design the connector and the cable preparation process for ITT six fiber cable, rather than the six fiber Siecor cable for which the prototype was designed. Changing to the ITT cable had more impact on the development of the preparation processes than it had on the design of the connector hardware. The ITT cable has a silicone elastomeric buffer layer and Hytrel jacket around each fiber, whereas the original Siecor cable had lacquer coated fiber in a loose buffer jacket. The fiber dimensions also differed, as shown in the following table:

	Siecor	ITT
Core diameter (μm)	63	50
Glass outer diameter (μm)	125	125
Numerical Aperture (N.A.)	0.21	0.23-0.28

The smaller core and higher N.A. of the ITT fiber make alignment more critical than it was for the Siecor fiber. In addition, the Siecor fiber, with its thin lacquer coating, has good concentricity of the core relative to the coating diameter*. The ITT buffer layer is not controlled to maintain precise concentricity, so it must be removed to expose the bare fiber. The method developed for protecting the fiber from loss of strength is described in a later section of this report.

Other changes incorporated in the final design were:

1. Improvements in cable strength member retention.
2. Cable strain relief to prevent sharp bends in the fiber cable at the connector.
3. Gasket seals to prevent entrance of water and dust in the connected mode.
4. Redesign of the fiber clamping system for improved fiber retention, reduction of number of parts to be handled, and easier assembly.
5. Redesign of the slug and piston block to provide a single part for field assembly, rather than many small parts.

The redesigned connector is shown in Figure 5. The Kevlar cable strength members are retained by an aluminum alloy nut, part no. 5 in the figure,

---

*It should be pointed out that Siecor has, in the past year, changed their fiber coating method, making it similar to the ITT design.

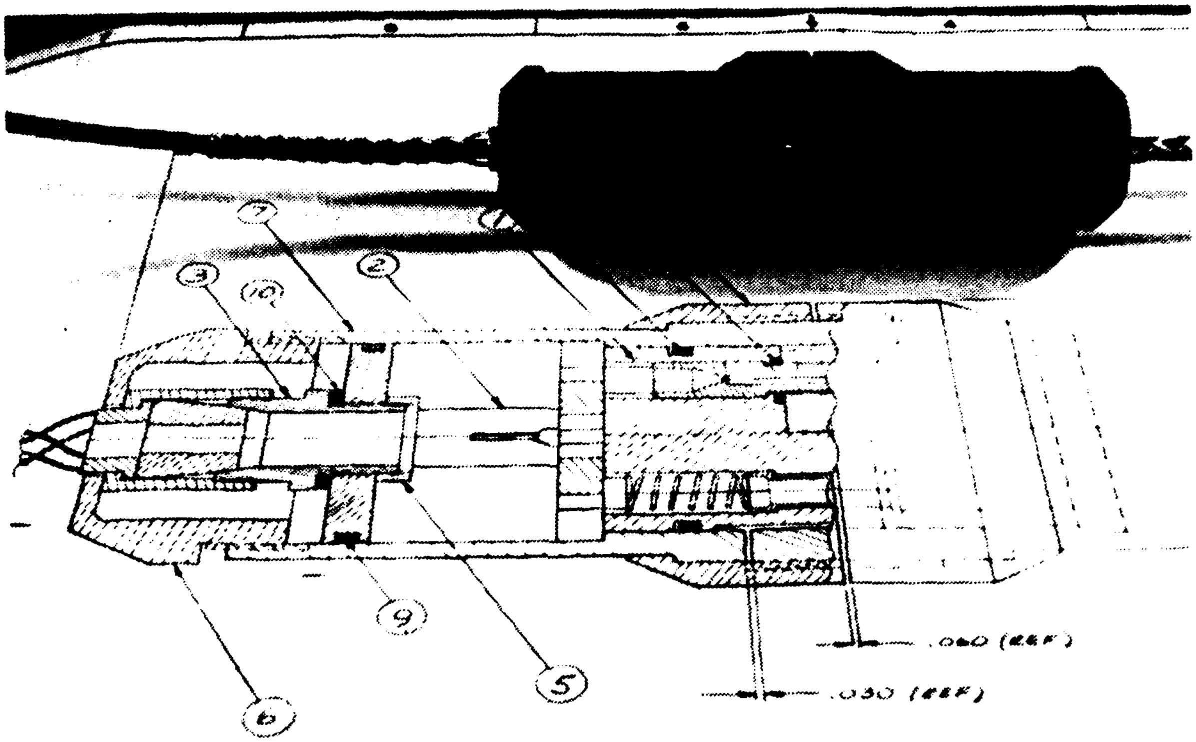


Figure 5

6 CHANNEL HERMAPHRODITIC CONNECTOR

FINAL MODEL - ASSEMBLY DRAWING

attached to the Kellems* grip body, part no. 3. Cable strain relief is provided by the Kellems mesh grip, extending from the opening in the connector cover. O-ring gasket seals are provided at points where moisture might otherwise enter the connector (parts 9, 10, 11 and 12). A rubber bushing seals tightly around the cable, as part of the Kellems grip assembly. The fiber clamp assembly (part no. 2) replaces the original clamp tree and separate two-piece fiber clamps of the prototype model. The slug and piston support assembly is pre-assembled at the factory, and contains three glass alignment guides in plastic slugs, and three spring loaded pistons.

Figure 6 shows the slug and piston support assembly snapped together with the assembled cable, Kellems grip and fiber clamp assembly, prior to insertion into the connector shell. The assembled, but unmated, hermaphroditic connector is shown in Figure 7. The slugs, which contain the alignment guides, and the ends of the pistons are visible in each connector half. A mated hermaphroditic connector is pictured in Figure 8 and the bulkhead version is shown in Figure 9.

---

*The Kellems grip is manufactured by Kellems Division, Harvey Hubbell, Inc., Stonington, CT.

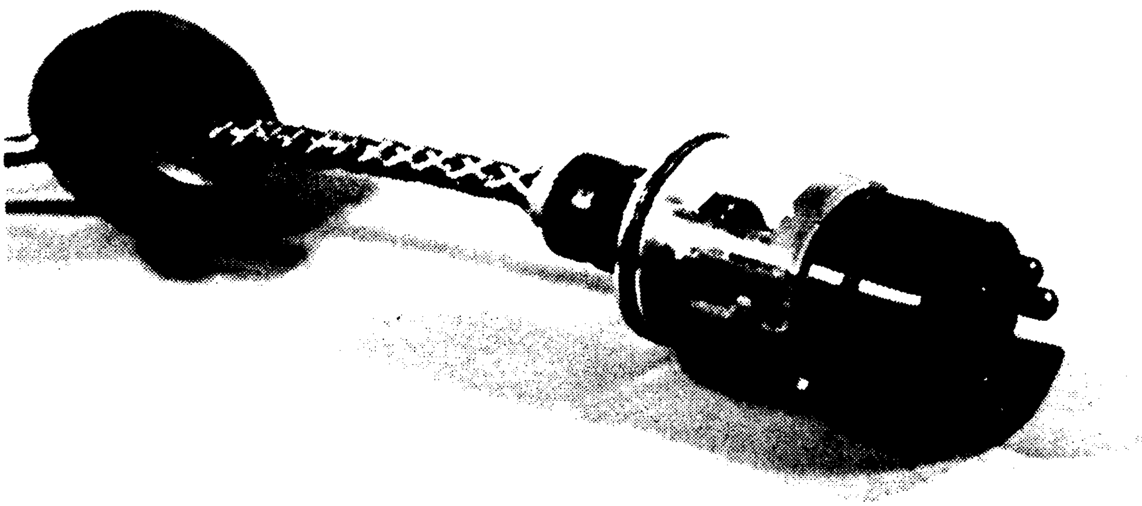


Figure 6
6 CHANNEL CONNECTOR
FINAL MODEL - INTERNAL SUBASSEMBLY

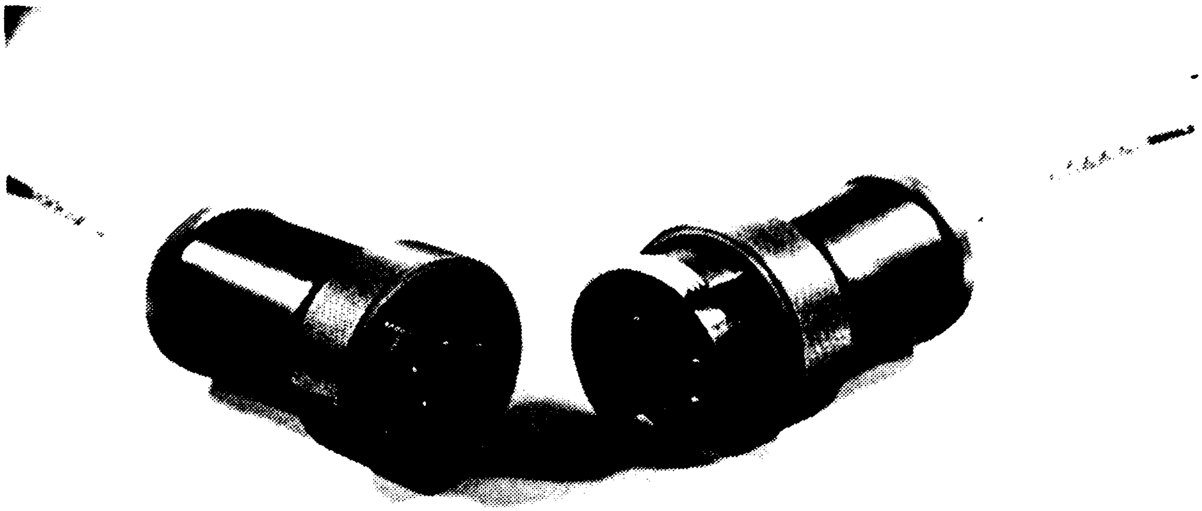


Figure 7
6 CHANNEL HERMAPHRODITIC CONNECTOR
FINAL MODEL - UNMATED HALVES

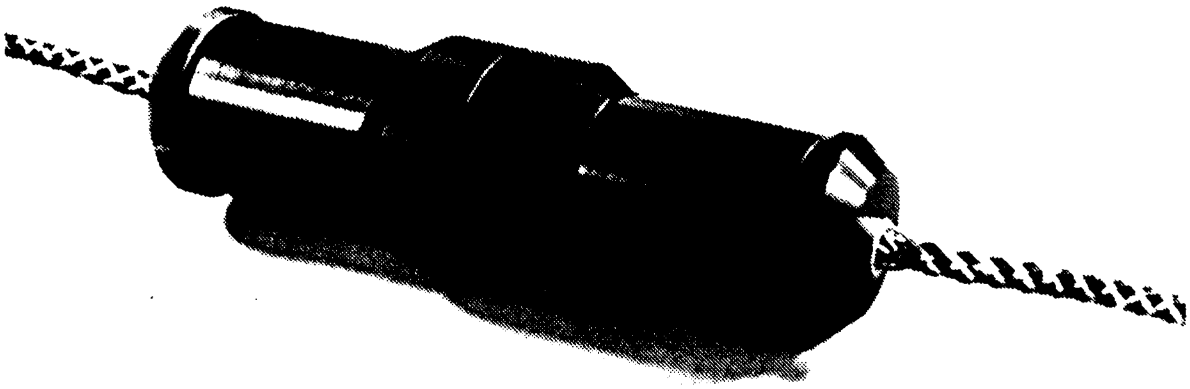


Figure 8
6 CHANNEL HERMAPHRODITIC CONNECTOR
FINAL MODEL - MATED

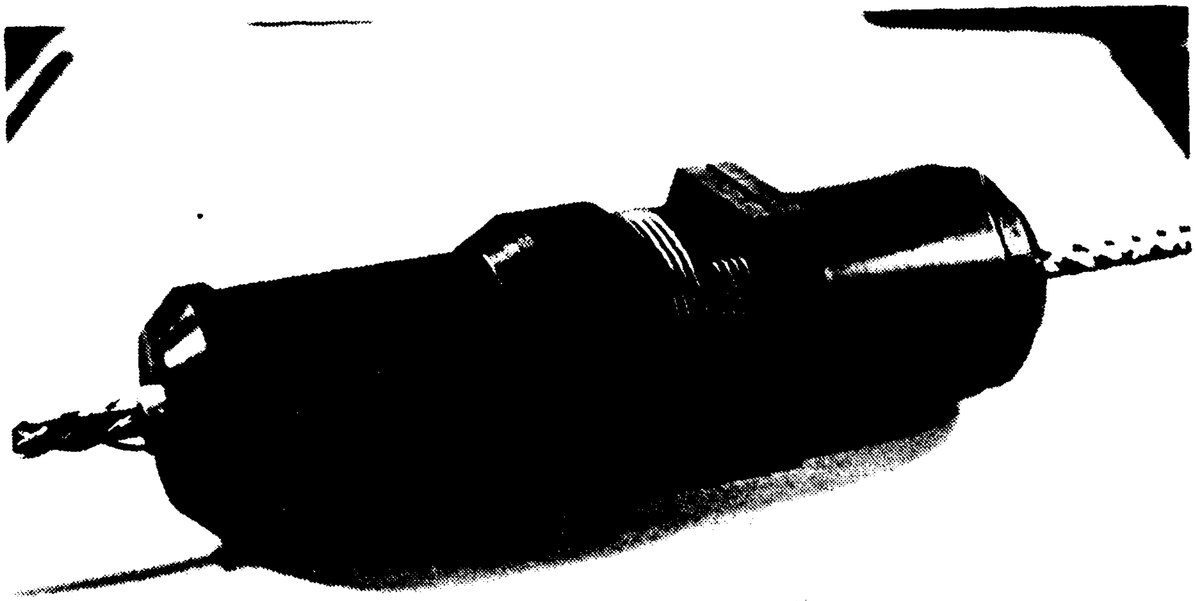


Figure 9
6 CHANNEL BULKHEAD CONNECTOR
FINAL MODEL - MATED

4.0 FIBER END PREPARATION

4.1 Scribing and Cleaving

Precise axial alignment of the fiber ends is basic to obtaining low loss connections. In the TRW connector, this alignment is provided by the four rod guide, described in a previous section. In addition, it is necessary to prepare the fibers in such a way that the cleaved ends are substantially perpendicular to the fiber axis. The ends must also have a smooth, mirror finish to avoid light and scattering losses characteristic of ends having hackle, or other surface irregularities.

We have been able to obtain low losses with a scribe and cleave procedure, by controlling the tension and torsion forces while the fiber cleavage occurs. This is especially important for the ITT fiber, with its smaller core and larger N.A. than that of the earlier Corning fiber (Siecor cable).

Figure 10 shows the importance of the fiber face angle on connection loss. These experimental data were obtained with 125μ silica fibers. Loss, in dB, is plotted against the sum of the fiber face angles. Two readings were taken with each pair of fibers; one fiber being rotated until maximum loss was obtained, and then turned 180^{o}, and the loss calculated again. A straight line approximation for the

EFFECT OF FIBER FACE ANGLE ON LIGHT POWER LOSS

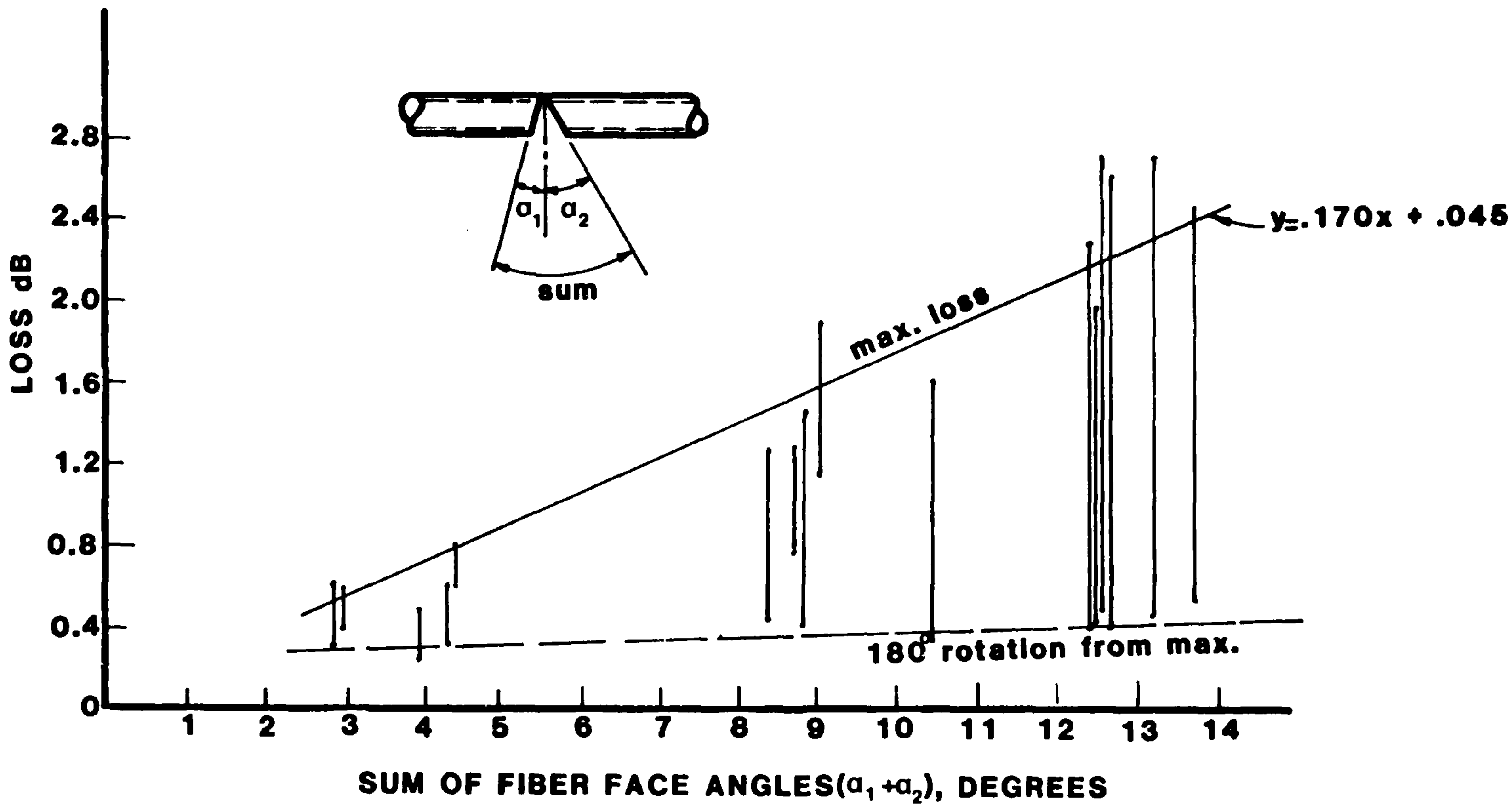


Figure 10

EFFECT OF FIBER FACE ANGLE
ON LIGHT POWER LOSS

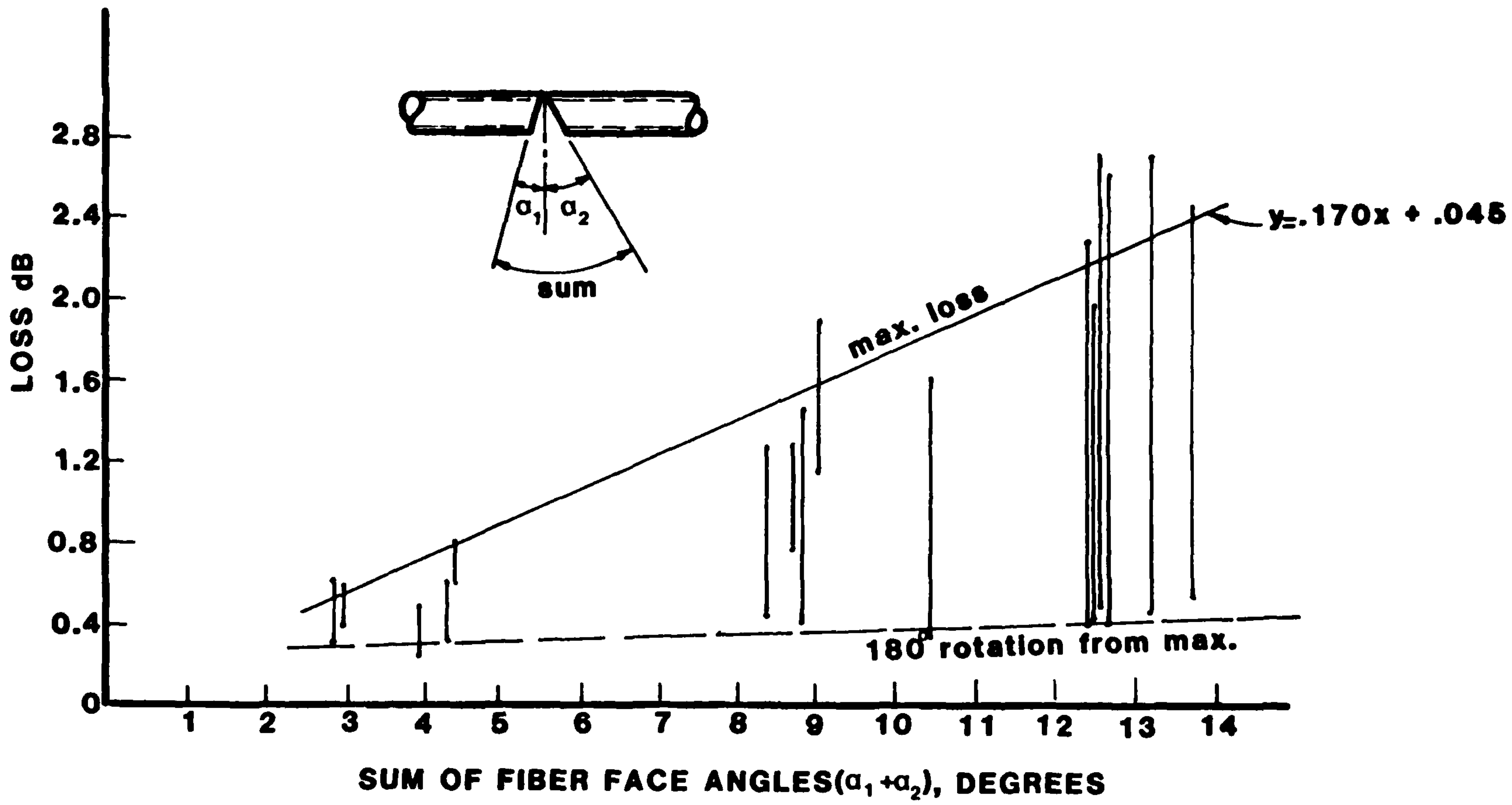


Figure 10

maximum loss was found by the linear regression method:

$$\text{dB loss} = .170(\alpha_1 + \alpha_2) + .045$$

The coefficient of determination is 0.9, indicating a reasonably good fit of the above equation to the experimental data.

It is apparent from Figure 4 that the sum of the fiber face angles should be less than 4^{o}, to be sure that the loss contribution of end angles will be less than 1.0 dB. Variable results were obtained with our initial scribing attempts. During our investigations, we found that small torsion angles applied to the fiber during scribing caused angular cleavage of the fiber.

An experiment was performed to measure the effect of fiber twist on cleavage angle. A 200 gm weight was suspended by a fiber of 10.2 cm or 15.2cm length. A twist angle of 90^{o} was imparted to the fiber. The fiber was scribed with a tungsten carbide knife edge. The results of the experiment are plotted in Figure 11. The average cleavage angle of 3.5^{o} for a 6^{o}/cm twist angle is in close agreement with some of the data reported by Saunders[5].

A machine was designed and built for scribing the six fibers, after insertion in the connector clamp assembly. A photograph of the scribing machine is shown in Figure 12. Control of the fiber twist angle, and an applied breaking force of 180 gm, produces cleavage

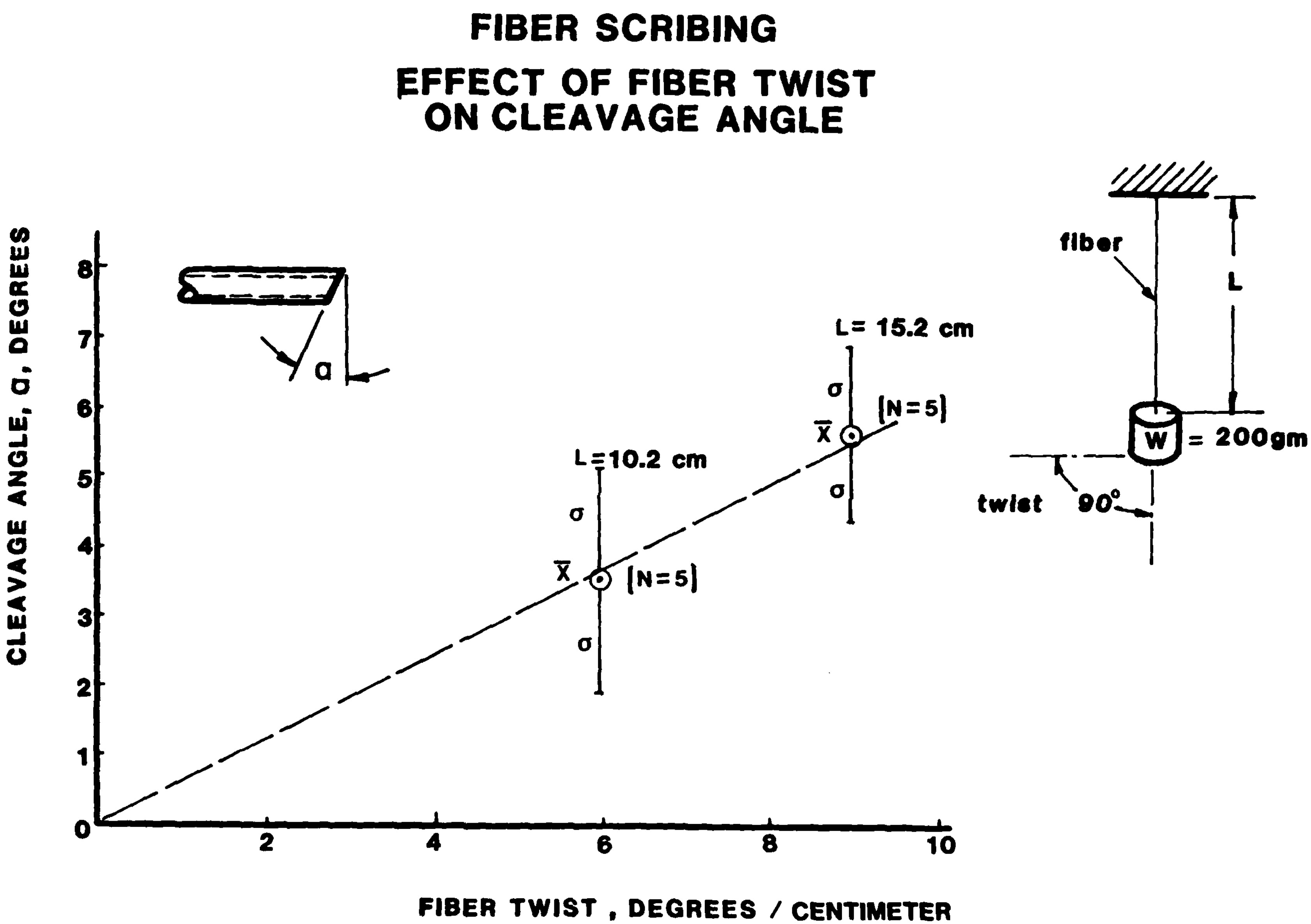

FIBER SCRIBING
EFFECT OF FIBER TWIST
ON CLEAVAGE ANGLE
CLEAVAGE ANGLE, α, DEGREES
8
7
6
5
4
3
2
1
0
2
4
6
8
10
FIBER TWIST , DEGREES / CENTIMETER
α
L=10.2 cm
σ
X̄
(N=5)
σ
L= 15.2 cm
σ
X̄
(N=5)
σ
fiber
L
W
= 200gm
twist
90°

Figure 11

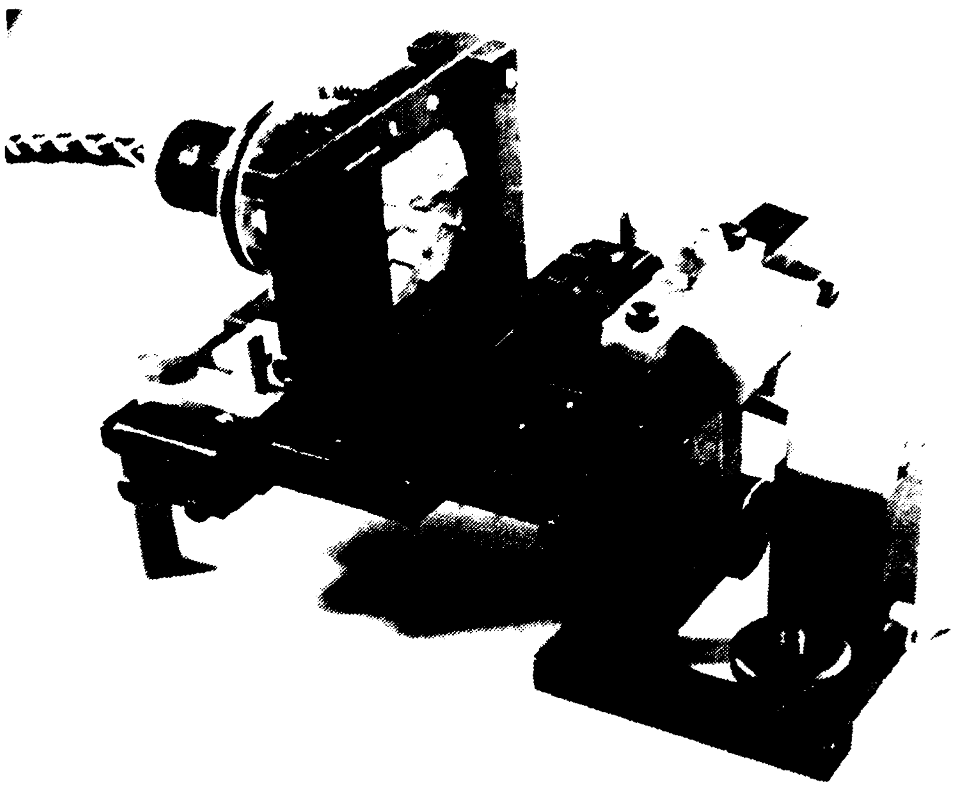


Figure 12
MACHINE FOR SCRIBING & CLEAVING
FIBERS IN 6 CHANNEL CONNECTOR

angles of 1.0° or less. The procedure of scribing before the breaking force is applied causes minimum angle on the fiber ends. See Appendix A, Assembly Procedure, for a description of the scribing/cleaving procedure, using the scribing machine.

4.2 Recoating

The fibers in the original Siecor cable had a thin lacquer coating. Because the coating was thin, and concentric with the core, alignment was easily achieved, without removing the coating.

The ITT fibers do not have the protective lacquer coating. The RTV silicone buffer coating, being soft, and not necessarily concentric, is unsuitable for alignment in the four-rod guide. It is necessary, therefore, to strip the Hytrel jacket, as well as the buffer layer, leaving the bare silica fiber exposed. If unprotected, the silica glass rapidly loses strength due to the action of moisture in the air. Tensile strength of silica glass, if prepared and coated with epoxy acrylate in a laboratory environment may be as high as 700 KSI. If unprotected, and touched with the fingers,strength may be immediately reduced to 345MN/m^2. It is possible, with protection, to maintain fiber strength to as high as 1400 to 2000 MN/m^2, initially.[6]

In short, to maintain connector reliability with time, and with repeated matings, it is necessary to provide some protection of the

bare fibers after removal of the silicone buffer layer. Considerable effort was devoted to determining a method for protecting the fiber without having a deleterious effec on alignment in the guide.

The first approach considered was to provide a fixture with special blades to strip the Hytrel and silicone while the fiber end was immersed in a liquid coating material. A fixture was constructed for this purpose, but was found to be cumbersome, particularly insofar as handling six fibers individually is concerned.

Of the coating materials tried, one of the most promising was a EPO-TEK 394, manufactured by Epoxy Technology, Inc., Billerica, Mass. With care, a thin, even coating of this material can be applied and cured at room temperature or, in seconds with a small amount of heat. There is some skill required in obtaining a smooth coating. The main disadvantage is that small bits of the EPO-TEK may be abraded from the fiber surface, in repeated matings. These pieces of material can potentially interfere with contact of the fiber faces, causing an increase in light loss.

The material finally selected for protecting the fibers is a silane liquid, trimethylchlorosilane. This has been found to maintain the fiber strength sufficiently to withstand well over 1000 bends as incurred to the fiber upon entrance to the alignment guide. The silane film on the fiber is extremely thin, thus causing little or no interference with core to cladding concentricity. Trimethylchlorosilane prevents attack of the silica by OH- ions, by combining

with the surface molecules. The coating, then, is essentially monomolecular.

The procedure developed involves immediately dipping the fiber ends in the silane after stripping away the RTV silicone layer. This operation is described in Appendix A in more detail.

5.0 CONNECTOR PERFORMANCE

5.1 Tests Performed

The basic test of connector performance is the measurement of insertion loss. In addition, the following environmental and durability tests were run:

1. Vibration, MIL-STD-202E, method 204C, Condition A (1.524 mm amplitude, or 10g, 10 to 500 Hz).
2. Thermal shock, MIL-STD-202E, Method 107D, Condition A ($-55^{\circ}C$, $25^{\circ}C$, $85^{\circ}C$, $25^{\circ}C$).
3. Mating durability: 1000 cycles. Free running nut torque, < .085 Nm.

Insertion loss measurements were monitored during and after the above tests.

5.2 Insertion Loss Measurements

A schematic drawing of the insertion loss test setup is shown in Figure 13. A helium-neon laser ($\lambda = 632.8$ nm) was used as the light source. The beam expander for the original tests of the prototype connector consisted of a collimating lens system. The cleaved fiber ends were rigidly retained in a holder in the expanded laser beam. In an effort to obtain better stability of the light modes in each fiber of the cable, a single lens at the laser output was substituted

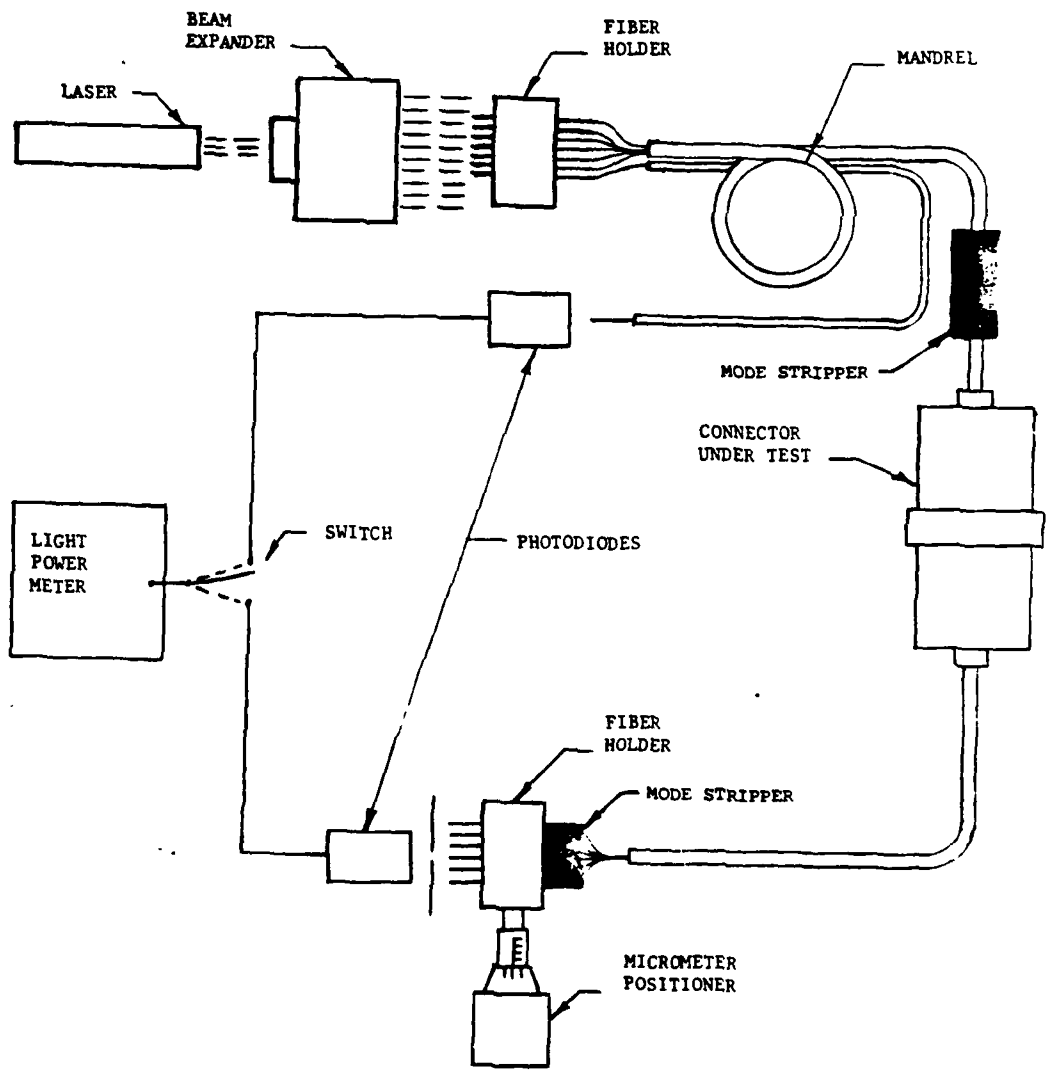


Figure 13

INSERTION LOSS TEST SETUP

for the expander/collimater. The six fibers in the cable, and the reference fiber, were cemented to the lens to maintain positional stability. The reference fiber serves to monitor variations in laser output.

Both six fiber cable and the single fiber reference cable were wound around a 2.54cm diameter mandrel to provide mode mixing, and high order modes were stripped from the cladding before and after passing through the connector. The six fiber cable was joined in the test connector beyond the mode mixer. Following the connector, the six prepared fiber ends were secured in a holder. For the tests of the original prototype connector, the fiber holder was adjustable with a micrometer actuated positioner to locate each fiber, in turn, in front of a slit, behind which was a photodiode. A revision was made in this arrangement before testing the final connectors. Instead of having the fiber holder adjustable, the position of the masking slit was movable. In this way, each fiber was exposed individually by moving the slit, and each fiber remained directed toward a specific area on the photodetector, thus assuring repeatable results.

The reference fiber was positioned in front of a separate PIN diode The outputs from the two diodes were compared on the same light power meter, by switching from one diode to the other.

The insertion loss is the light power loss due to introduction of the

connector in the cable. In our tests, we measured the power transmitted by the cable, then cut it in the middle, and assembled it with the connector, as described above. The light output was again measured. Insertion loss is expressed in decibels, calculated as follows:

$$\text{dB loss} = 10 \log_{10} \frac{\text{light power without connector}}{\text{light power with connector}}$$

When making the light power measurements, with the connector in place, each fiber reading is compared with the reference fiber and ratio corrections are made.

In the original tests with the prototype connector, it was found that the initial readings taken through the Siecor cable, without the connector, varied with time up to $\pm$ 0.5dB, compared with the laser monitoring fiber. Because of this, some readings indicated that negative losses occured, due to the low loss levels and to the cyclic variations in cable: monitor ratio. The variations could have been caused by mode shifts in the expanded laser beam, as well as to thermal effects on the mounting plate causing dimensional changes in the approximately 60 cm distance between laser and fiber input ends. In the final test setup with ITT cable, fiber ends were attached with an optical adhesive to a lens located about three inches from the laser output port.

After the first prototype connector was introduced into the Siecor cable, six sets of output readings were made for each of the six fibers to obtain

averages and to minimize the effects of variations in the power output ratio with time. The calculated mean values of six readings on each the fibers ranged from 0.05 to 1.02 dB insertion loss. The 36 measurements, taken together, have mean ($\overline{X}$) and standard deviation (σ) values as follows:

	$\overline{X}$	σ
dB loss	0.55	0.41

See Table 1 for dB loss in each fiber.

The 0.55dB loss is considered to be excellent for connection of dry, scribed and cleaved fibers.

Tests of the final design with ITT cable produced somewhat higher average values for the six fibers, but lower standard deviation:

	$\overline{X}$	σ
dB loss	1.02	0.16

This is still good for dry connections. As previously mentioned, the ITT fiber has a smaller core diameter, and larger N.A., compared with the Siecor fiber used with the prototype model. Both factors can contribute to higher light power losses with the ITT fiber.

TABLE 1

INSERTION LOSS (dB) - PROTOTYPE & FINAL MODELS

FIBER NO.	F_1	F_2	F_3	F_4	F_5	F_6	$\bar{X}$	σ
PROTOTYPE (with Siecor cable)	1.02	0.05	0.33	0.76	0.93	0.20	0.55	0.41
FINAL MODEL (with ITT cable)	0.80	0.89	1.07	1.13	1.00	1.24	1.02	0.16

5.3 Environmental Tests

5.3.1 Vibration Test

The MIL-STD-202E, method 204C, Condition A test specifies that the component under test be subjected to 12 complete cycles of 10 Hz to 500 Hz in each of three mutually perpendicular planes. Calculations indicated that the fiber alignment guide configuration prevents the fiber ends from moving away from the cusp. Also no fiber resonance occurs within the 10 Hz to 500 Hz frequency range.

Tests were made of the prototype model, with Siecor cable, and of the final designs: one hermaphroditic and one bulkhead connector. Each fiber was monitored for one complete cycle in each of the three vibration planes. No sudden changes in light transmission were observed, on either a digital light power meter or an oscilloscope.

The insertion loss excursions (maxiumum minus minimum dB loss) for the prototype model in the vibration test are shown in Table 2. The average of these excursions is 0.16 dB. Table 3 gives the initial and final insertion losses for the vibration test of the prototype, showing a slight upward shift in the average. This increase was well within the predicted variations in a stable environment.

TABLE 2

INSERTION LOSS EXCURSION, dB - VIBRATION TEST

PROTOTYPE MODEL

FIBER NO.	F_1	F_2	F_3	F_4	F_5	F_6	$\overline{X}$	σ
X axis	0.37	0.31	0.20	0.19	0.16	0.11	0.22	0.10
Y axis	0.30	0.18	0.19	0.07	0.07	0.05	0.14	0.10
Z axis	0.08	0.14	0.23	0.12	0.09	0.05	0.12	0.06
				ALL READINGS			0.16	0.09

TABLE 3

INSERTION LOSS CHANGE - VIBRATION TEST

PROTOTYPE MODEL

36 CYCLES, 10 Hz - 500 Hz

FIBER NO.	INITIAL		ΔdB AFTER VIBRATION
1	1.02		0.11
2	0.05		0.35
3	0.33		0.41
4	0.76		0.04
5	0.93		-0.10
6	0.20		0.06
		$\overline{X}$	0.15
		σ	0.20

Vibration data for the final models, hermaphroditic and bulkhead, are summarized in Tables 4 through 7. The excursions in dB loss are given in Tables 4 and 6; the change in dB (ΔdB) for each fiber in Tables 5 and 7. The initial values given are approximate, based upon later readings taken to reestablish the reference light levels upon which dB loss calculations are based. Because of the time involved in developing the fiber preparation, and changes in the reference fiber output due to transporting the test setup to the vibration equipment, the apparent losses were in the order of 2 to 4 dB. The reference shift was discovered after many of the tests had been run. Corrections were made near the end of the test program, by measuring light input to each fiber in the test connector and comparing the output at a second set of connections downstream. The approximate loss values shown in Tables 5 and 7 are the readings taken with new connections after other tests were run. The ΔdB values are those that actually occurred due to the vibration test.

The vibration test had little or no effect on light conduction, and caused no damage to the mechanical integrity of the connectors.

5.3.2 Thermal Shock Test

The effect of thermal shock on dB loss of each fiber of the prototype model, with Siecor cable, is shown in Figure 14. Light power measurements were made at each temperature: 25^{o}, -55^{o}, 25^{o} and 85^{o}, through

TABLE 4

INSERTION LOSS EXCURSION, dB - VIBRATION TEST

HERMAPHRODITIC - FINAL MODEL

FIBER NO.	F_1	F_2	F_3	F_4	F_5	F_6	$\bar{X}$	σ
X axis	0.65	0.34	0.25	0.23	0.27	0.37	0.35	0.16
Y axis	0.71	0.50	0.50	0.28	0.51	0.70	0.53	0.16
Z axis	0.35	0.26	0.38	0.27	0.23	0.10	0.27	0.10
					ALL READINGS		0.38	0.18

TABLE 5

INSERTION LOSS CHANGE - VIBRATION TEST

HERMAPHRODITIC - FINAL MODEL

36 CYCLES, 10 Hz - 500 Hz

FIBER NO.	INITIAL*	Δ dB AFTER VIBRATION
1	1.0	0.14
2	0.8	-0.15
3	1.0	-0.10
4	1.0	-0.12
5	1.1	-0.12
6	1.1	-0.22
	$\overline{X}$	-0.10
	σ	0.12

*APPROXIMATE: SEE TEXT

TABLE 6

INSERTION LOSS EXCURSION, dB - VIBRATION TEST

BULKHEAD - FINAL MODEL

FIBER NO.	F_1	F_2	F_3	F_4	F_5	F_6	$\bar{X}$	σ
X axis	0.18	0.35	0.36	0.34	0.18	0.26	0.28	0.08
Y axis	0.26	0.64	0.45	0.47	0.21	0.12	0.36	0.19
Z axis	0.51	0.37	1.21	0.65	0.51	0.35	0.60	0.32
					ALL READINGS		0.41	0.25

TABLE 7

INSERTION LOSS CHANGE - VIBRATION TEST

BULKHEAD - FINAL MODEL

36 CYCLES, 10 Hz - 500 Hz

FIBER NO.	INITIAL*	Δ dB AFTER VIBRATION
1	1.0	-0.09
2	0.8	-0.01
3	1.0	-0.26
4	1.0	-0.13
5	1.1	0.12
6	1.1	0.18
	$\overline{X}$	-0.03
	σ	0.16

*APPROXIMATE: SEE TEXT

EFFECT OF THERMAL SHOCK ON LIGHT POWER LOSS PROTOTYPE MODEL

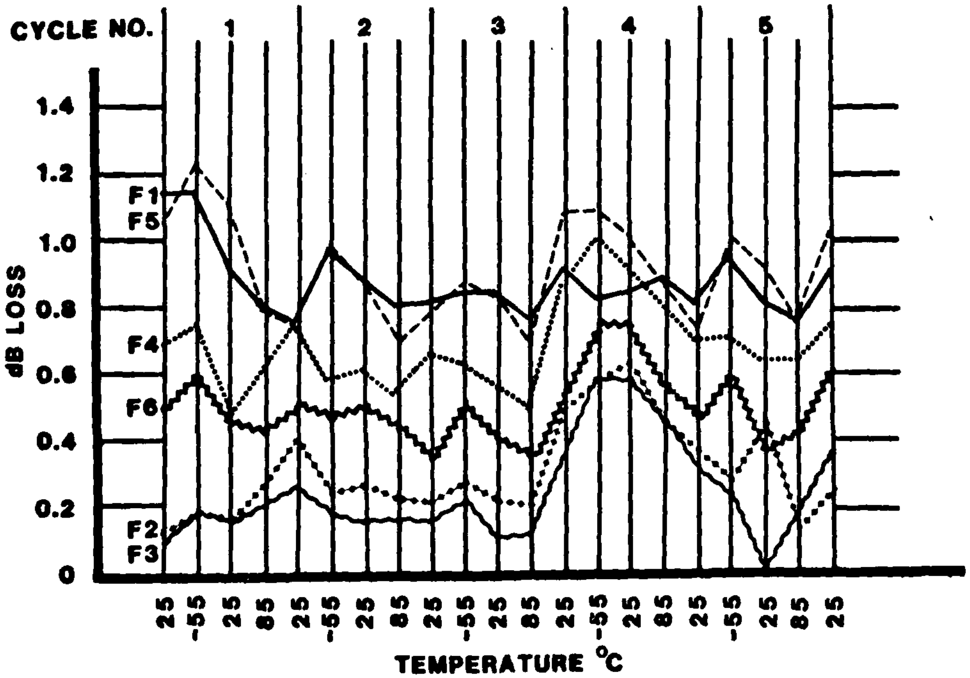


fig.14

five complete cycles. The calculated dB loss is plotted for each of the six fibers and did not exceed about 1.2 dB. Loss variation was within the range of the inherent variations in the test setup.

Graphs of dB loss through the five temperature cycles are shown for the final hermaphroditic and bulkhead models in Figures 15 and 16, respectively. The indicated initial loss levels are based on readings taken later to reestablish the reference, as stated in the preceding section.

Initial readings were less than 1.4 dB. Several fibers in each connector increased to 1.5 to 2.4 dB on the cold side of the cycle (-55°C). The maximum loss value reached by any fiber connection at 25° or 85° was 1.54 dB. The reason for the higher losses at -55°C were not definitely determined. Possible explanations are: microbending of fibers at the ends of the jackets caused by the hardening of the Hytrel and silicone buffer layers; or, condensation and freezing of moisture trapped in the connector. The latter does not seem probable since the prototype model, which was not sealed, did not exhibit the low temperature effect.

One channel (F5) in the bulkhead connector lost continuity after four cycles, due to a break in the fiber. Fiber F5 frequently functioned poorly, due to the difficulty in stripping; probable cause of failure was a nick in the fiber. There was no mechanical damage to the connectors caused by thermal shock.

EFFECT OF THERMAL SHOCK ON LIGHT POWER LOSS
HERMAPHRODITIC–FINAL MODEL

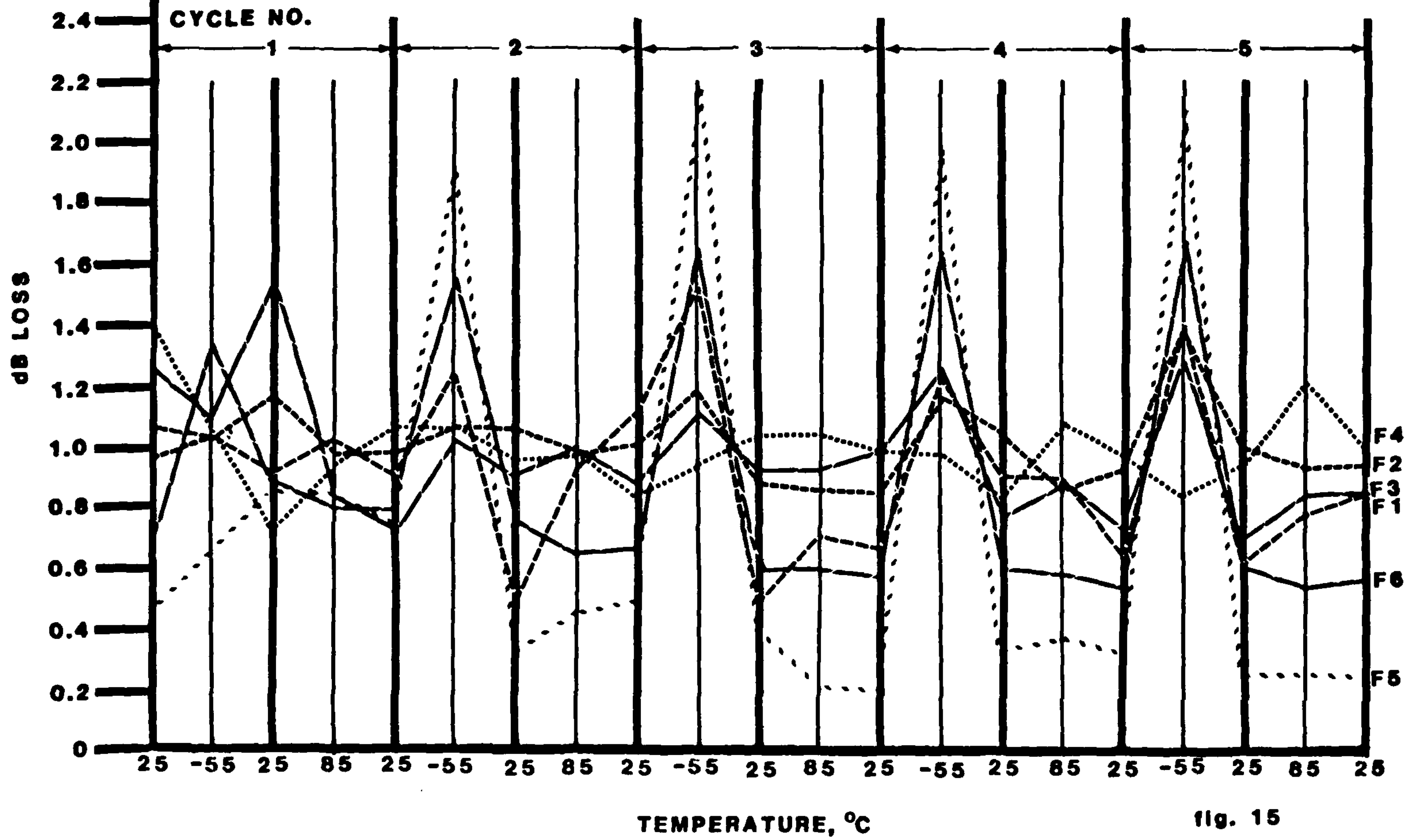


fig. 15

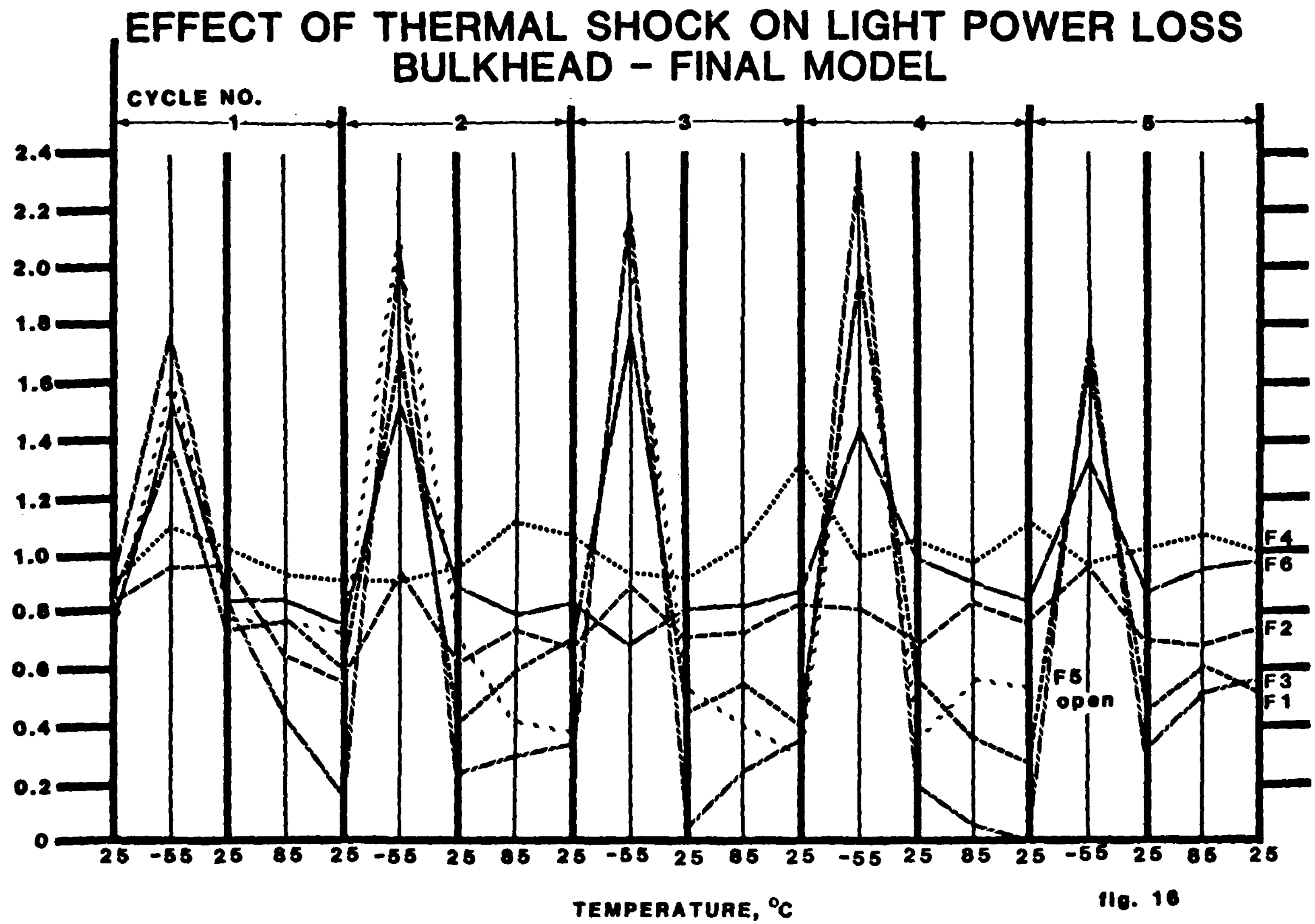

EFFECT OF THERMAL SHOCK ON LIGHT POWER LOSS
BULKHEAD - FINAL MODEL
CYCLE NO.
1
2
3
4
5
dB LOSS
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
25 -55 25 85 25 -55 25 85 25 -55 25 85 25 -55 25 85 25 -55 25 85 25
TEMPERATURE, °C
F4
F6
F2
F3
F1
F5 open

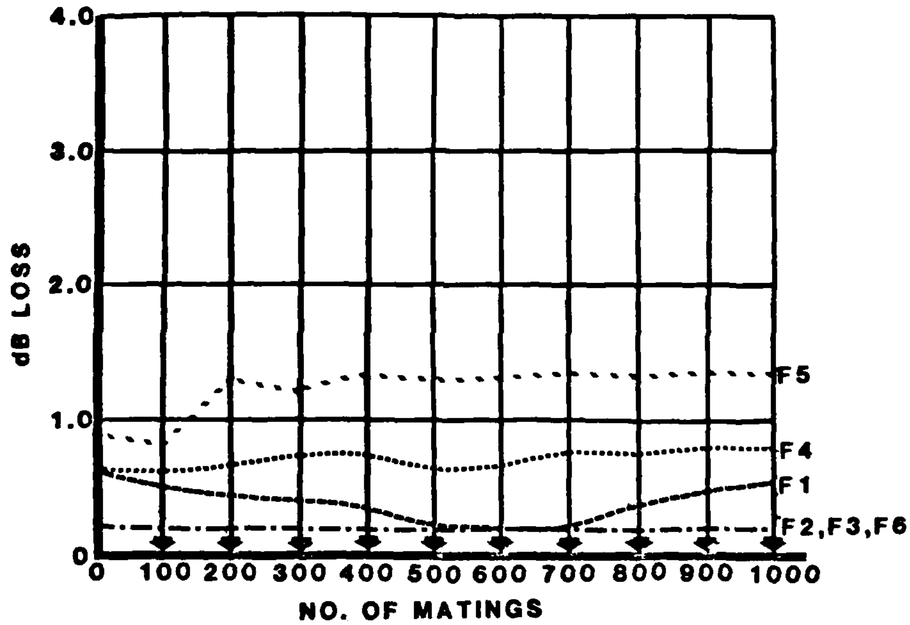
fig. 16

5.3.3 Mating Durability

The prototype model, with Siecor cable, was subjected to 1000 mating cycles. The results of dB loss measurements at 100 cycle increments are shown in Figure 17. All of the fiber connections had losses of less than 1.0 dB, initially, and only one connection (F5) exceeded 1.0 dB at any time. F2, 3, and 6 had low losses which, in some cases, were calculated to be negative losses. These apparently negative losses are attributable to the cycling of the light level "seen" by a single fiber in the expanded laser beam.

Some difficulties were experienced in mating tests of the hermaphroditic final model of the connector with ITT cable. The procedures for stripping and coating were still going through a developmental phase. The stripped fibers had withstood other tests without breaking, but three of the six fibers did not survive to the scheduled 1000 mating cycles (see Table 8). The two fibers which have always been difficult to strip in the ITT cable sample broke during the test (F1 and F5). F2 lost its signal after 300 matings, but partially regained it at 900 cycles, with the loss increasing by about 10 dB. A check of fiber lengths indicated that the combined lengths of mated fibers was up to .010 over the maximum allowed, which causes sharper bends in the fiber loop, giving rise to high bending stress. The higher stress, plus the fiber damage during stripping and recoating, could account for high readings obtained and early failure of some of the fibers. The initial loss readings in Table 8 are based on later readings, with newly scribed fiber when the reference levels were reestablished, as

EFFECT OF MATING CYCLES
ON dB LOSS - PROTOTYPE MODEL
SIECOR CABLE



NOTE: DOWNWARD POINTING ARROWS INDICATE
CALCULATED dB LOSS IS LESS THAN 0.2 dB

Figure 17

TABLE 8

REPEATED MATING CYCLES

HERMAPHRODITIC FINAL MODEL

ITT CABLE

FIBER NO.	INITIAL dB LOSS*	NO. OF MATINGS BEFORE LOSS OF SIGNAL	REMARKS
F1	1.0	600	FIBER BROKEN
F2	0.8	300	REGAINED SOME OUTPUT(+10dB) AFTER 900 CYCLES
F3	1.0	>1000	FIBER OK
F4	1.0	>1000	FIBER OK
F5	1.1	50	FIBER BROKEN
F6	1.1	>1000	FIBER OK

*APPROXIMATE: SEE TEXT

TABLE 8

REPEATED MATING CYCLES

HERMAPHRODITIC FINAL MODEL

ITT CABLE

FIBER NO.	INITIAL dB LOSS*	NO. OF MATINGS BEFORE LOSS OF SIGNAL	REMARKS
F1	1.0	600	FIBER BROKEN
F2	0.8	300	REGAINED SOME OUTPUT(+10dB) AFTER 900 CYCLES
F3	1.0	>1000	FIBER OK
F4	1.0	>1000	FIBER OK
F5	1.1	50	FIBER BROKEN
F6	1.1	>1000	FIBER OK

*APPROXIMATE: SEE TEXT

discussed in a previous section.

The results of the repeated matings of the bulkhead version of the final model are shown in Figure 18. All of the fibers withstood 1000 mating cycles, due to the improved stripping procedures, application of the trimethylchlorosilane to retain fiber strength, as well as to the reduced stress with decreased bending in the overtravel loop. The losses increased from approximately 1 dB to 2 dB for four channels, and to 4 and 11dB for the other two. When the connector was disassembled, fiber ends cleaned, and reassembled, the loss levels returned to the original values.

The free running coupling nut torque, when measured before and after the 1000 mating cycles, was less than 0.007 Nm, well within the 0.085 Nm requirement.

In summary, the connector withstands 1000 mating cycles without damage, when used with the lacquer coated Siecor fiber. When the ITT fiber is properly prepared, the fibers will also withstand the 1000 matings. The increase in loss with some fibers was reversible by cleaning the fibers ends.

EFFECT OF MATING CYCLES ON dB LOSS

BULKHEAD FINAL MODEL
ITT CABLE

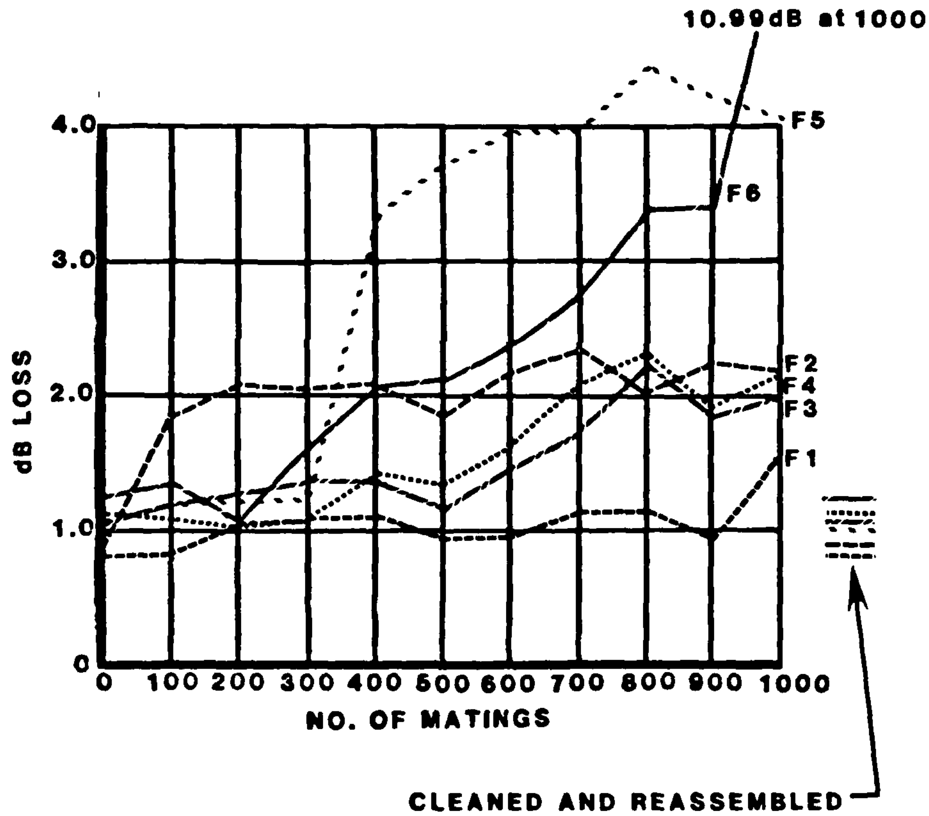


Figure 18

6.0 CONCLUSIONS

1. The TRW six channel connector has average losses of 0.55 dB per channel when used with the Siecor 63μm core, lacquer coated fiber. Losses average 1.02 dB per channel with the ITT 50 μm core, Hytrel/silicone RTV buffered fiber.

2. Procedures were developed, under this contract, for stripping the Hytrel and silicone buffer layers from the ITT fiber and providing a strength-retaining fiber treatment with a silane compound.

3. The connector is capable of withstanding vibration, thermal shock and 1000 mating cycles without loss of signal or mechanical damage.

7.0 RECOMMENDATIONS

1. A protective system should be developed to prevent incursion of dirt and water into the connector alignment guides, when the connector halves are separated. (Such a system is currently being developed at TRW R&D Labs.)

2. It would be advantageous to the installation of connectors, and other optical components, if the optical fiber manufacturers were to coat the fibers, immediately after drawing, with a silane or silane/silicone fluid. Such a process would retain the inherent strength of glass, both in the cable and in situations where the fiber jacket must be removed.

3. The light losses incurred in the connector can be greatly reduced, to less than 0.5 dB, by filling the alignment guide with an index matching fluid. The "wet" connection minimizes loss due to surface irregularities and reflections at the fiber ends. A reservoir to supply a silicone fluid, for multiple matings of the Optalign(R) connector, has been developed at the TRW R&D Laboratories. The reservoirs can easily be used in a multiple channel connector of the type described in this report. An additional advantage of the silicone wet connection is that water is excluded, and dirt particles are washed away, from the fiber junction.

8.0 References

1. Hodge, Malcolm H., "A Low Loss Single Fiber Connector Alignment Guide", Fiber Optic Conference, 1978, Proceedings, pp. 111-115.

2. Ryley, James F., "Optical Fiber Communications Cable Connector", Semi - Annual Report for Period 1 May - 1 Nov. 1979, CORADCOM Contract No. 79-0772-1.

3. U.S. Patent No. 4,192,575, "Guide-Connector Assembly for Joining Optical Fibers and Method of Making Guide Therefor", M.H. Hodge, assignor to TRW, Inc.

4. U.S. Patent No. 4,225,214, "Connector Construction", 9/30/80, M.H. Hodge, R.E. Lumpp, Mark Margolin, assignors to TRW, Inc.

5. Saunders, M.J., "Torsion Effects on Fractured Fiber Ends", Applied Optics, Vol. 18, No. 10, 15 May 1979.

6. Fariyal, B.K. and Krause, J.F., "Ensuring the Mechanical Reliability of Lightguide Fiber", The Western Electric Engineer, Vol. XXIV, No. 1, Winter 1980.

7. Woods, John G., Hodge, Malcolm H., Ryley, James F., Jr., "A Military Six Fiber Hermaphroditic Connector", Fiber Conference - 1980, San Francisco, CA., September, 1980.

8. Woods, John G., Hodge, Malcolm H., Ryley, James F., Jr., "A Military Six Fiber Hermaphroditic Connector", 29th International Wire and Cable Symposium, Cherry Hill, NJ, November, 1980.

APPENDIX A

ASSEMBLY PROCEDURE

Six Fiber Connector Half with ITT Cable.

Assembly No. RM79 -296 - 00 - H-1000

I. Preparation of cable end and cable grip.

A. Slide the following parts, in order shown, on the cable:

1. Cover.

2. Kellems Grip.

a. Compression Nut.

b. Mesh.

c. Bushing.

B. Remove approximately 13 cm of the outer black cable jacket.

1. Slit jacket lengthwise with razor blade or sharp knife.

2. Cut jacket circumferentially, 13 cm from the end. (Do not cut through the yellow Kevlar strength members.)

3. Pull back Kevlar strands to expose inner black cable jacket.

4. Remove exposed inner cable jacket, using a razor blade or sharp knife, as in I. B. 1 and 2, above. Seven color coded Hytrel jacketed optical fibers are now exposed (six fibers and a central strength member in some cables).

II. Assembly of cable end to clamp assembly.

A. Assemble O-Ring over pipe thread end of Kellems Grip Body.

B. Screw Kellems Grip Body into threaded hole of Clamp Assembly.

C. Assemble O-Ring to disc groove of Clamp Assembly.

D. Feed the optical fibers through the Kellems Grip Body, while holding the Strength Nut, loosely around the optical fibers inside the clamp assembly.

E. Distribute the Kevlar strands through the side openings of the Clamp Assembly, but not through the Strength Nut.

F. Position the unstripped end of the cable at the end of the Kellems Grip Body, inside the Clamp Assembly.

G. Slide the rubber Bushing and Compression Nut up to the threaded Body and tighten the Nut.

H. Screw the Strength Nut on to the Grip Body, capturing the Kevlar strands.

I. Cut the excess Kevlar strands close to the Strength Nut, using a sharp knife or scissors.

J. Insert the six individual fibers in the clamp tree slots, using the insertion tool blade. (Select color code order consistent with mating connectors.)

K. Adjust fibers to make them parallel to the connector axis.

III. Stripping and recoating of fibers.

A. Using the .025 No-Nik stripping tool, remove approximately a one inch length of the Hytrel jacket from one of the fibers. Then remove the remaining length of jacket with the No-Nik tool to within ¼ inch of the clamp tree face.

B. Immediately dip the stripped fiber in a vial of the silane solution, to cover the stripped length. Withdraw the fiber slowly; 5 second minimum for complete withdrawl.

C. Repeat steps II A. and B. for each of the remaining 5 fibers.

D. Strip any of the remaining silicone buffer layer from the fiber to within ½ inch of the clamp tree face, using Kimwipes or lens tissue soaked in trimethychlorosilane liquid. <u>Do not touch the bare silica fiber with the fingers</u>. If the silicone buffer continues to stick to the fiber, a silicone stripper may be used; soak for 30 seconds and wipe with tissue. Then, immediately dip the fiber in the silane solution, again.

IV. Scribing and cleaving of fibers.

A. Set the scribing machine for the "short" fiber position. (The short fibers will enter the three Slugs in a future operation.)

B. Insert the Clamp Assembly in the holder on the scribing machine, with one of the fibers selected for the slug side at the bottom position. While inserting the Clamp Assembly, feed the bottom

fiber into the fiber holding clamp on the scribing machine.

C. Make sure the weight is in the raised position, controlled by the lever at the end of the machine.

D. Tighten the fiber holding clamp screw, with the pull yoke in the vertical position.

E. Scribe the fiber by sliding the chisel blade from one side to the other.

F. Gently release the weight by turning the lever. The fiber will cleave at the scribed point.

G. Repeat steps IV B. through F. for the other two fibers on one side of the 1.58 mm slot in the clamp tree.

H. Position the clamp assembly holder for the "long" fiber position. (The long fibers will enter the three retractable pistons in the next assembly operation.)

I. Repeat steps IV B. through G. until the three long fibers are properly scribed and cleaved.

J. Examine the cleaved fiber ends with a 10X magnifier. The ends must appear to be perpendicular to the fiber axis.

V. Final assembly.

A. Select a pre-assembled Support Assembly. This assembly contains 3 Slugs with Glass Guides, as well as 3 spring loaded Pistons.

B. Assemble O-Ring to the Support Assembly.

C. Assemble 3 O-Rings, one around each slug.

D. Assemble the Support Assembly to the Clamp Assembly, with the short fibers entering the slugs and the long fibers entering the pistons. (Care must be taken that the fibers are parallel to the connector axis and do not hang up on the springs or support walls as the assembly is made.) Press the Grippers (P/N H-1000-6) into the slot in the clamp tree.

E. Assemble Coupling Nut to the Shell or, if the bulkhead connector is being made, assemble 2 Flange Nuts to the Bulkhead Shell.

F. Slide Support and Clamp Assembly into the Shell (or the Bulkhead Shell). The keyway on the Support must engage the locating pin on the inside of the Shell. (The O-rings may be lubricated with silicone grease to ease assembly.)

G. Screw the Cover to the Shell, completing the assembly of a connector half.

H. Repeat all steps, section I through V, for the mating connector half, giving consideration to color coded fiber orientations.

APPENDIX B

Parts List

TRW/Cinch 6 Fiber Connector

1.	Six Fiber Connector	RM79-296-00-H-1000	
2.	Shell	RM79-296-00-H-1000	-1
3.	Coupling Nut	RM79-296-00-H-1000	-2
4.	Cover	RM79-296-00-H-1000	-3
5.	Piston/Slug Support	RM79-296-00-H-1000	-4
6.	Disc	RM79-296-00-H-1000	-5
7.	Gripper	RM79-296-00-H-1000	-6
8.	Clamp Tree	RM79-296-00-H-1000	-7
9.	Strength Nut	RM79-296-00-H-1000	-8
10.	Bulkhead Shell	RM79-296-00-H-1000	-9
11.	Clamp Assembly	RM79-296-00-H-1000	-10
12.	Flange Nut	RM79-296-00-H-1000	-11
13.	Support Assembly	RM79-296-00-H-1000	-12
14.	Spring	RM79-296-00-H-1000	-15
15.	O-Ring Parker #129	RM79-296-00-H-1000	-17
16.	O-Ring Parker #115	RM79-296-00-H-1000	-18
17.	O-Ring Parker #127	RM79-296-00-H-1000	-19
18.	O-Ring Parker #010	RM79-296-00-H-1000	-20
19.	Collar	RM79-296-00-H-1000	-21
20.	Collar	RM79-296-00-H-1000	-22
21.	Alignment Guide	463-99-99-990	
22.	Piston	474-11-95-766	
23.	Slug	474-11-95-767	

Materials List

TRW/Cinch 6 Fiber Connector

1. Single edge industrial razor blade.
2. No - Nik wire stripper, #025.
3. Insertion tool blade.
4. Glass vials.
5. Silicone stripper, Cee Bee #105HF, McGean Chemical Co., Inc.
   Downey, CA 90241.
6. Trimethylchlorosilane.
7. TRW Scribing Machine, Six Fiber Scriber - Model 2.
8. Silicone grease.

DISTRIBUTION LIST

Defense Technical Information Center
Attn: DTIC-TCA
Cameron Station (Building 5)
Alexandria, VA 22314
(12 Copies)

Director
National Security Agency
Attn: TDL
Fort George G. Meade, MD 20755

Code R123, Tech Library
DCA Defense Comm Engrg Ctr
1860 Wiehle Avenue
Reston, VA 22090

Defense Communications Agency
Technical Library Center
Code 205 (P.A. Tolovi)
Washington, DC 20305

Office of Naval Research
Code 427
Arlington, VA 22217

GIDEP Engineering & Support Dept.
TE Section
P.O. Box 398
Norco, CA 91760

CDR, MIRCOM
Redstone Scientific Info Center
Attn: Chief, Document Section
Redstone Arsenal, AL 35809

Commander
HQ Fort Huachuca
Attn: Technical Reference Div
Fort Huachuca, AZ 85613

Commander
US Army Electronic Proving Ground
Attn: STEEP-MT
Fort Huachuca, AZ 85613

Commander
USASA Test & Evaluation Center
Attn: IAO-CDR-T
Fort Huachuca, AZ 85613

Director
Naval Research Laboratory
Attn: Code 2627
Washington, DC 20375

Command, Control & Communications Div.
Development Center
Marine Corps Development & Educ Comd
Quantico, VA 22134

Naval Telecommunications Command
Technical Library, Code 91L
4401 Massachusetts Avenue, NW
Washington, DC 20390

Rome Air Development Center
Attn: Documents Library (TILD)
Griffiss AFB, N.Y. 13441

AFGL/Sull
S-29
Hanscom AFB, MA 01731

HQDA (DAMA-ARP/DR. F.D. Verderame)
Washington, DC 20310

Director
US Army Human Engineering Labs
Aberdeen Proving Ground, MD 21005

CDR, AVRADCOM
Attn: DRSAV-E
P.O. Box 209
St. Louis, MO 63166

Director
Joint Comm Office (TRI-TAC)
Attn: TT-AD (Tech Docu Cen)
Fort Monmouth, N.J. 07703

Commander
US Army Satellite Communications Agcy
Attn: DRCPM-SC-3
Fort Monmouth, N.J. 07703

Dir.,US Army Air Mobility R&D Lab
Attn: T. Gossett, Bldg. 207-5
NASA Ames Research Center
Moffett Field, CA 94035

HQDA (DAMO-TCE)
Washington, DC 20310

Deputy for Science & Technology
Office, Assist Sec Army (R&D)
Washington, DC 20310

Commander, DARCOM
Attn: DRCDE
5001 Eisenhower Avenue
Alexandria, VA 22333

CDR, US Army Signals Warfare Lab
Attn: DELSW-OS
Arlington Hall Station
Arlington, VA 22212

CDR, US Army Signals Warfare Lab
Attn: DELSW-AQ
Arlington Hall Station
Arlington, VA 22212

Commander
US Army Logistics Center
Attn: ATCL-MC
Fort Lee, VA 22801

Commander
US Army Training & Doctrine Command
Attn: ATCD-TEC
Fort Monroe, VA 23651

Commander
US Army Training & Doctrine Command
Attn: ATCD-TM
Fort Monroe, VA 23651

NASA Scientific & Tech Info Facility
Baltimore/Washington Intl Airport
P.O. Box 8757, MD 21240

Project Manager, ATACS
Attn: DRCPM-ATC (Mr. J. Montgomery)
Fort Monmouth, N.J. 07703

TRI-TAC Office
Attn: TT-SE (Dr. Pritchard)
Fort Monmouth, N.J. 07703

CDR, US Army Research Office
Attn: DRXRO-IP
P.O. Box 12211
Research Triangle Park, NC 27709

Director
N.S. Army Material Systems Analysis Actr.
Attn: DRXSY-MP
Aberdeen Proving Ground, MD 21005

Advisory Group on Electron Devices
201 Varick Street, 9th Floor
New York, N.Y. 10014

Advisory Group on Electron Devices
Attn: Secy, Working Group D (Lasers)
201 Varick Street
New York, N.Y. 10014

TACTEC
Battelle Memorial Institute
505 King Avenue
Columbus, OH 43201

Ketron, Inc.
Attn: Mr. Frederick Leuppert
1409 Wilson Bldg.
Arlington, VA 22209

R.C. Hansen, Inc.
P.O. Box 215
Tarzana, CA 91356

CDR, US Army Avionics Lab
AVRADCOM
Attn: DAVAA-D
Fort Monmouth, N.J. 07703

Times Fiber Comm, Inc.
358 Hall Avenue
Wallingford, Conn. 06492

Bell Northern Research
P.O. Box 3511, Station C
Ottawa, Canada K1Y 4H7

Dir.,US Army Air Mobility R&D Lab
Attn: T. Gossett, Bldg. 207-5
NASA Ames Research Center
Moffett Field, CA 94035

HQDA (DAMO-TCE)
Washington, DC 20310

Deputy for Science & Technology
Office, Assist Sec Army (R&D)
Washington, DC 20310

Commander, DARCOM
Attn: DRCDE
5001 Eisenhower Avenue
Alexandria, VA 22333

CDR, US Army Signals Warfare Lab
Attn: DELSW-OS
Arlington Hall Station
Arlington, VA 22212

CDR, US Army Signals Warfare Lab
Attn: DELSW-AQ
Arlington Hall Station
Arlington, VA 22212

Commander
US Army Logistics Center
Attn: ATCL-MC
Fort Lee, VA 22801

Commander
US Army Training & Doctrine Command
Attn: ATCD-TEC
Fort Monroe, VA 23651

Commander
US Army Training & Doctrine Command
Attn: ATCD-TM
Fort Monroe, VA 23651

NASA Scientific & Tech Info Facility
Baltimore/Washington Intl Airport
P.O. Box 8757, MD 21240

Project Manager, ATACS
Attn: DRCPM-ATC (Mr. J. Montgomery)
Fort Monmouth, N.J. 07703

TRI-TAC Office
Attn: TT-SE (Dr. Pritchard)
Fort Monmouth, N.J. 07703

CDR, US Army Research Office
Attn: DRXRO-IP
P.O. Box 12211
Research Triangle Park, NC 27709

Director
N.S. Army Material Systems Analysis Actr.
Attn: DRXSY-MP
Aberdeen Proving Ground, MD 21005

Advisory Group on Electron Devices
201 Varick Street, 9th Floor
New York, N.Y. 10014

Advisory Group on Electron Devices
Attn: Secy, Working Group D (Lasers)
201 Varick Street
New York, N.Y. 10014

TACTEC
Battelle Memorial Institute
505 King Avenue
Columbus, OH 43201

Ketron, Inc.
Attn: Mr. Frederick Leuppert
1400 Wilson Bldg.
Arlington, VA 22209

R.C. Hansen, Inc.
P.O. Box 215
Tarzana, CA 91356

CDR, US Army Avionics Lab
AVRADCOM
Attn: DAVAA-D
Fort Monmouth, N.J. 07703

Times Fiber Comm, Inc.
358 Hall Avenue
Wallingford, Conn. 06492

Bell Northern Research
P.O. Box 3511, Station C
Ottawa, Canada K1Y 4H7

Commander
ERADCOM
Fort Monmouth, N.J. 07703
Attn: DELET-D
DELSD-L-S
(2 Copies)

Commander
CORADCOM
Fort Monmouth, N.J. 07703
Attn: DRDCO-COM-D
DRDCO-SEI
DRDCO-COM-RM-1
(20 Copies)

ITT Electro-Optical Prod Div
7635 Plantation Road
Roanoke, VA 24019

Corning Glass Works
Telecommunication Prod Dept
Corning, New York 14830

Galileo Electro-Optics Corp.
Galileo Park
Sturbridge, MA 01518

Deutsch Co.
Elec Components Division
Municipal Airport
Banning, CA 92220

Martin Marietta Corp.
Orlando, FL

Electronics Group of TRW, Inc.
401 N. Broad Street
Philadelphia, PA 19108

Hughes Aircraft Corporation
Tucson Systems Engrg Dept.
P.O. Box 802, Room 600
Tucson, AZ 85734
Attn: Mr. D. Fox

Valtec Corporation
Electro Fiber Optic Div
West Boylston, MA 01583

Hughes Research Laboratory
3011 Malibu Canyon Road
Malibu, CA 90265
Attn: Dr. R. Abrams

Belden Corporation
Technical Research Center
2000 S. Batavia Avenue
Geneva, IL 60134
Attn: Mr. J. McCarthy

Optelecom, Inc.
15940 Shady Grove Road
Gaithersburg, MD 20760

Bell Telephone Laboratories
Whippany Road
Whippany, N. J. 07981
Attn: Mr. G. A. Baker

Hughes Aircraft Company
Connecting Devices Division
17150 Von Karman Avenue
Irvine, CA 92714
Attn: Mr. J. Maranto

Harris Electronics Systems Division
P.O. Box 37
Melbourne, FL 32901
Attn: Mr. R. Stachouse
Fiber Optics Plant
Rodes Boulevard

ITT Defense Communications Division
492 River Road
Nutley, N.J. 07110
Attn: Dr. P. Steensma

Commander
Naval Ocean Systems Center
Code 8346
San Diego, CA 92152
Attn: Mr. D. Williams

GTE Sylvania Inc.
Communications System Division
189 B Street
Needham Heights, MA 02194
Attn: Mr. J. Concordia

Commander
Naval Ocean Systems Center
Code 4400
San Diego, CA 92152
Attn: Mr. G. Kosmos

Commander
Naval Avionics Facility
Code D831
Indianapolis, IN 46218
Attn: Mr. R. Katz

Commanding General
Wright-Patterson AFB, OH 45433
AFAL/AAD-2
Attn: Mr. K. Trumble

Commanding General
Hanscom AFB, MA 01731
RADC/ESO
Attn: Dr. R. Payne

RSRE
St. Andrews Road
Malvern, Worcs, England
Attn: Mr. J. G. Milner

Commander
Naval Ocean Systems Center
Code 4400
San Diego, CA 92152
Attn: Mr. R. Lebduska

DAT

FILM